

267-21

CONTRACT REQUIREMENTS
Exhibit E, Para. 5.10

CONTRACT ITEM
13

MODEL
LEM

CONTRACT NO.
NAS 9-1100

Type II

Primary No. 668

Mission-Related Design Requirements for the
LEM Structural/Mechanical Subsystem
Apollo Mission Planning Task Force

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1. SUMMARY

The purpose of this report is to define the mission-related critical design requirements for the LEM Structural/Mechanical subsystem, and to examine the present subsystem capabilities relative to these requirements for both nominal and contingency situations.

Briefly, these requirements consist of protecting the crew and equipment from meteoroids and thermal extremes and providing them with a pressurized cabin, inflight and surface visibility, and the means to transfer with equipment to and from both the CSM and the lunar surface. There are also requirements for supporting allied subsystem equipment, docking on the CSM, and landing on the lunar surface.

The nominal mission requires the LEM Structural/Mechanical subsystem to interface with the launch vehicle, the CSM and the environments of space and the lunar surface. To ensure compatibility with these interfaces, the above requirements were superimposed on all phases of the nominal mission and, where applicable, were examined during contingency situations.

As a result of this examination, this report concludes that the Structural/Mechanical subsystem is being designed to the proper mission-related requirements with the following qualifications.

- Meteoroid protection should be increased to raise the level of crew safety.
- Provisions should be made to use the upper hatch as a backup route to and from the lunar surface in the event the front path is unusable.
- A means of accurately determining the altitude prior to touchdown should be implemented to prevent high landing velocities.
- A study should be made of the trade between guidance accuracy and structural weight to determine the penalties of accepting a less stringent alignment tolerance between the landing radar and the navigation base.

2. LEM STRUCTURAL/MECHANICAL SUBSYSTEMS DESCRIPTION

2.1 ASCENT STAGE

The Ascent Stage structure supports a cabin capable of operating as a pressurized vessel and in the zero pressure condition as required by the mission phase. The cabin holds all supplies required by the crew during its use and provides support for all controls and displays. Its atmosphere is controlled by the Environmental Control Subsystem (ECS).

Windows are located in the cabin surface for visual reference during the landing and rendezvous-docking operations. Two hatches are available for cabin ingress and egress. One hatch is located in the area of the docking structure for intra-vehicular transfer when docked to the CSM. The other is placed on the front face for convenience when transferring crew and equipment to and from the lunar surface and when the LEM is on the pad prior to launch.

Structural members support the propulsion system and provide correct positioning of the Reaction Control Subsystem (RCS) clusters relative to the body axes and C. G location. Guidance and navigation units requiring close tolerance alignment relative to dependent equipment are mounted on accurately positioned rigid members to ensure necessary alignment. An unpressurized area is provided with structural supports to accommodate the primary electrical power supplies (fuel cells) and equipment not requiring inflight crew attention. The supporting structure for this equipment also serves as a heat transfer link by permitting the flow of a mixture of water and glycol through it.

Concentric with the X axis (which is also the nominal center line of thrust of the ascent and descent engines) and on top of the ascent stage is a ring which provides a structural interface for joining the LEM to the CSM. It is compatible with the clamping mechanisms housed in the CM and ensures structural continuity for transmitting Service Propulsion System (SPS) thrust during midcourse correction and lunar orbit injection. Below this ring the drogue portion of the probe and drogue docking mechanism is secured when required during the docking operation to mate with the CM mounted probe, and when "out of crew compartment" stowage is required.

Supported externally by the ascent stage structure are the various antennas used by the Guidance and Communications Subsystems. Due to space limitations within the S-IVB adapter,

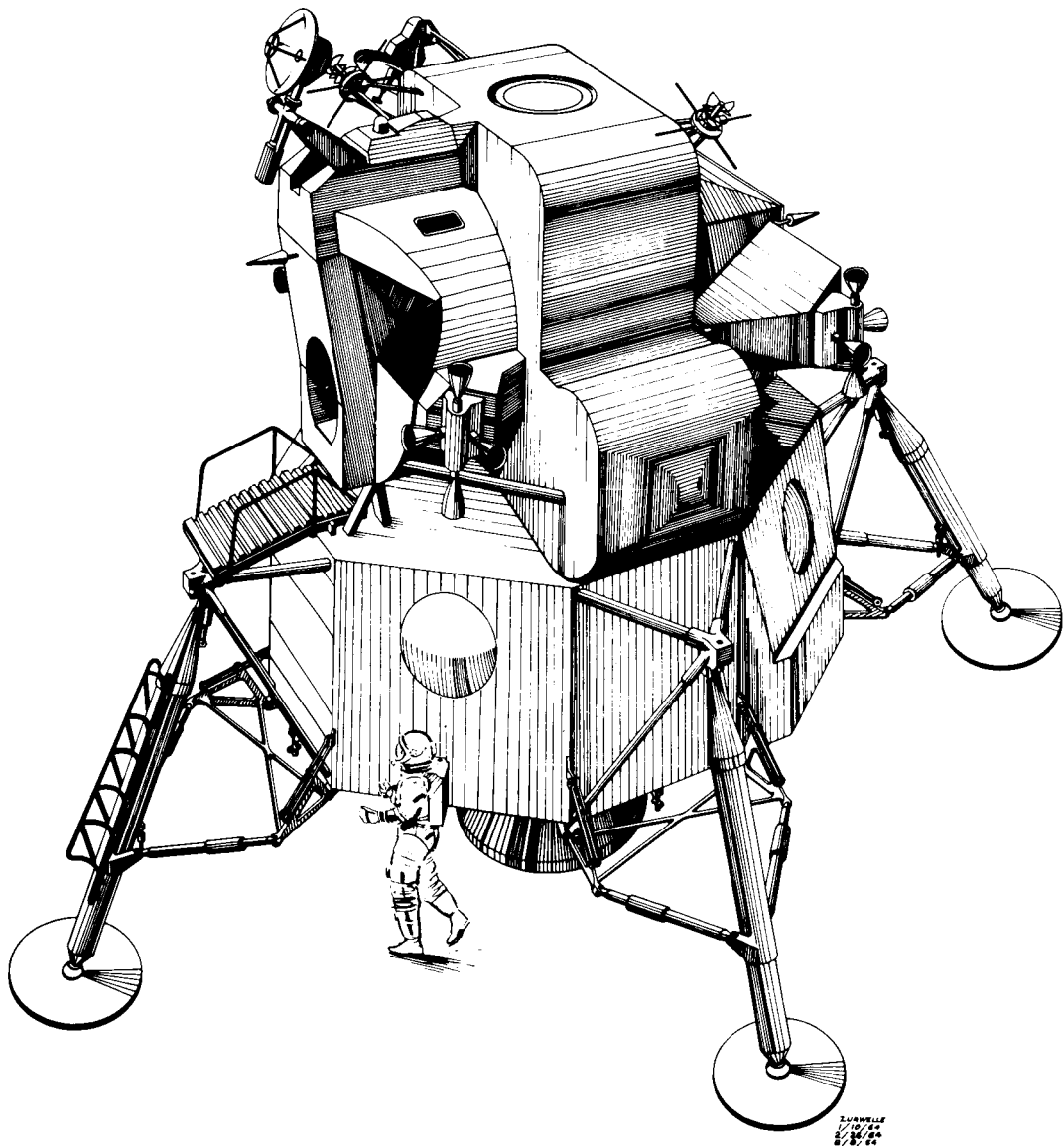


Fig. 1 Lunar Excursion Module

the S-Band steerable communications antenna must be stowed in a retracted position. During LEM checkout this antenna is extended by mechanical means to its operating position.

Varying 1 to 3 inches from the shell and external to it, is a covering of thin gage aluminum. Insulation consists of multiple layers of aluminized Mylar between these surfaces. This forms the thermal shielding necessary to provide, in conjunction with the ECS, acceptable temperatures within the LEM cabin, unpressurized equipment bays and tank areas. This shielding also provides some meteoroid protection.

2.2 DESCENT STAGE

The Descent Stage structure (Figure 2) provides the supporting points for securing the LEM within the S-IVB adapter. It also supports the landing gear and provides a launch pad for the Ascent Stage at lunar liftoff. The landing gear, because of space limitations within the S-IVB Adapter, is held by four electro-explosive devices (one for each leg) in a stowed position. During LEM checkout these devices are energized thru the redundant pyrotechnic circuit and, after initiation, release the four legs. After release the legs are spring-driven to their extended position and automatically locked.

Attenuation of landing loads is accomplished by the use of crushable metal cartridges confined within the primary and secondary struts (Figure 2). At the end of each leg is a pad which supports the LEM on soils having assumed bearing strengths per Reference 8.

Structure is provided for support of the descent engine, fuel, oxidizer and helium tanks, landing radar antennae, scientific equipment, oxygen tanks, hydrogen tanks and water tanks. The engine is in a separate compartment which is insulated to prevent excessive heat transfer from the engine during its operation.

The entire descent stage, except the surface exposed to engine heat, the landing radar, landing gear and exposed parts of the engine is enclosed by the same type of insulation used for the ascent stage.

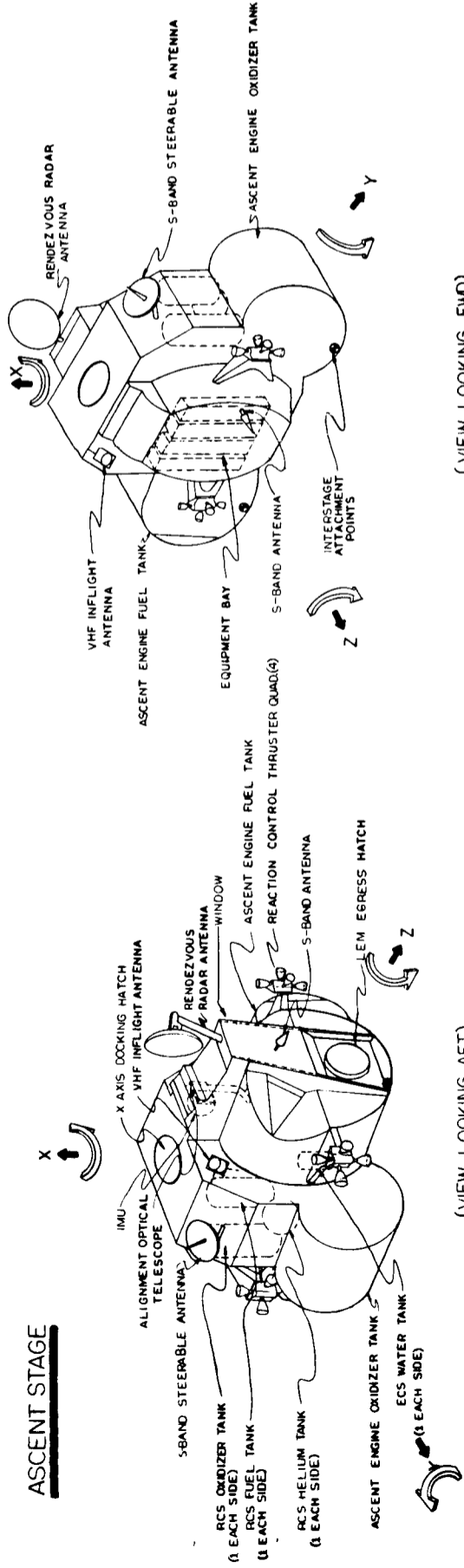
No special provisions are made for meteoroid protection, although limited protection is inherent with the existing structure and thermal shield.

2.3 INTERSTAGE CONNECTION

Joining the Ascent and Descent Stages together are four bolts and nuts which are units of a pyrotechnic system (See Figure 3). Upon command, each bolt is broken and each nut is

released (parts are contained) and the structural tie between stages is removed. The initiators in the bolts and nuts are energized by the current from two batteries and act simultaneously but either is capable of doing the job. Also linking the two stages is an electrical and hard line umbilical which is being led through two pyrotechnic devices which, when energized by the batteries, serve the bundle with a guillotine and linear shaped charge action. The hydrogen and oxygen, in the Descent Stage, that is required by the fuel cells in the Ascent Stage, flows through two quick disconnects in the area of the umbilical. These disconnects are spring loaded mechanisms that self seal when a depressing force is removed as staging occurs.

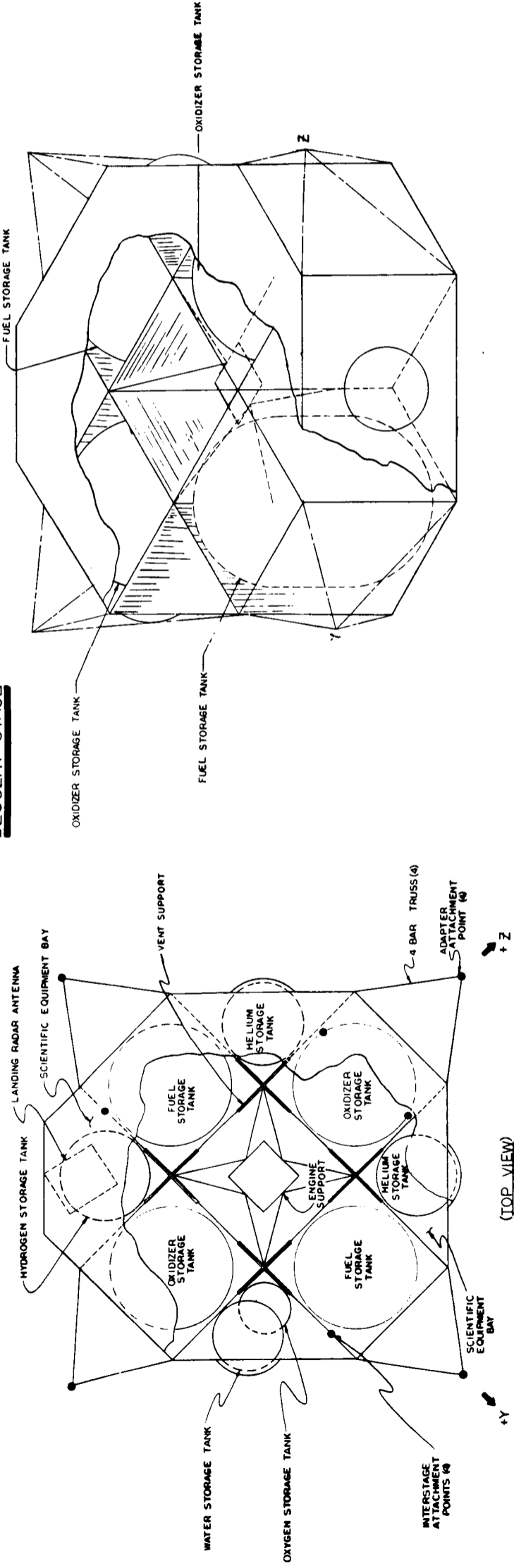
ASCENT STAGE



(VIEW LOOKING AFT)

(VIEW LOOKING FWD)

DESCENT STAGE



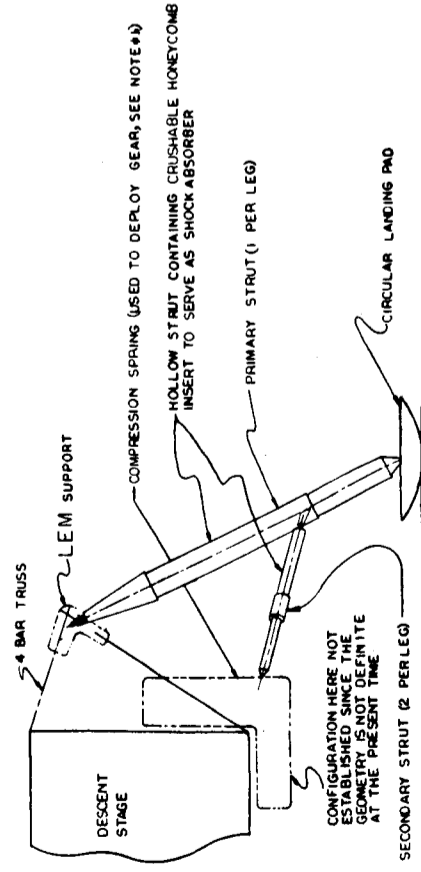
(TOP VIEW)

LANDING GEAR

(TYPICAL 4 PLACES)

(SIDE VIEW)

(TOP VIEW)



This diagram is the same as the Level 2, LEM Functional Configuration, Structural Subsystem, LDW-540-10010, Rev. A.

NOTES

1. COMPRESSION SPRING USED FOR DEPLOYMENT OF LANDING GEAR TO BE RELEASED BY MEANS OF EED MECHANISM TO BE USED NOT DETERMINED AT PRESENT.

ABBREVIATIONS

- LEM = LUNAR EXCURSION MODULE
- RCS = REACTION CONTROL SYSTEM
- ECS = ENVIRONMENTAL CONTROL SYSTEM
- SYS = SYSTEM
- WTS = WEIGHTS
- ANAL = ANALYSIS
- LR = LANDING RADAR
- ATT = ATTACHMENT
- H₂ = HYDROGEN
- STOR = STORAGE
- CM = COMMAND MODULE

Fig. 2 Structural Subsystem Functional Diagram

NOTES

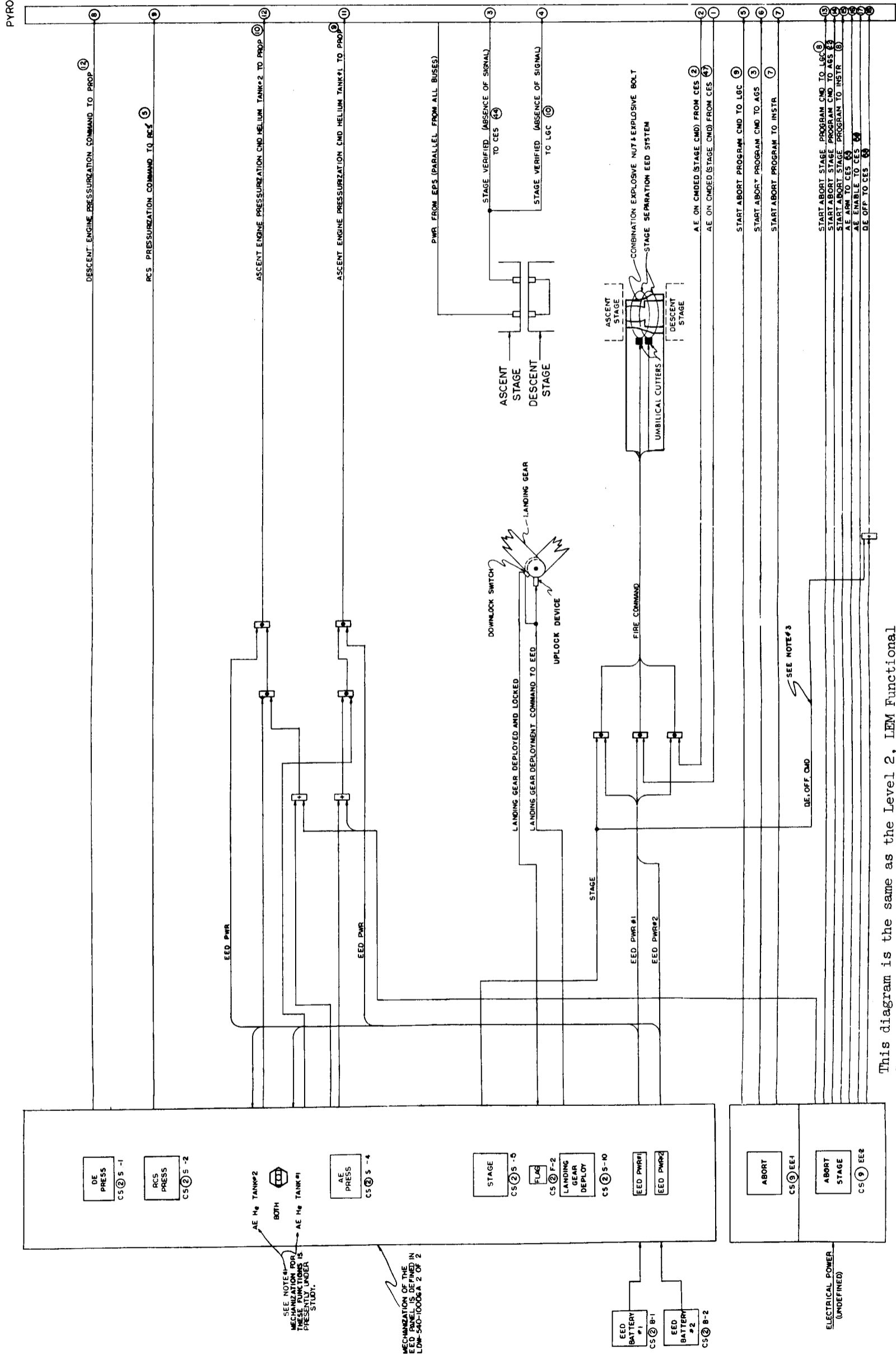
- 1. THESE FUNCTIONS ARE FOR EMERGENCY USE IN THE EVENT ONE OF THE TANKS IS PUNCTURED.
- 2. ALL EED FUNCTIONS SHOWN AS DOUBLE OUTPUTS TO THE EED PANEL HAVE 2 OR MORE PATHS OF OPERATION, DEPENDING UPON THE FINAL SYSTEM.
- 3. THE NEED FOR A DESCENT ENGINE OFF COMMAND FOR THE DIRECT STAGE FUNCTION IS PRESENTLY UNDER STUDY.

ABBREVIATIONS

- CS = CREW SYSTEMS
- CES = CONTROL ELECTRONICS SECTION
- PCS = REACTION CONTROL SUBSYSTEM
- PROP = PROPELLSION SUBSYSTEMS
- CMDED = COMMANDED
- LGC = LEM GUIDANCE COMPUTER
- AGS = ABORT GUIDANCE SECTION
- AE = ASCENT ENGINE
- INSTR = INSTRUMENTATION SUBSYSTEM
- DE = DESCENT ENGINE
- SL = SWITCH LIGHT
- PAR = POWER
- EIE = EMERGENCY INITIATE SWITCH
- EED = ELECTRO EXPLOSIVE DEVICE

SYMBOLS

- FUNCTIONAL AND GATE FUNCTIONAL INPUTS A AND B PROVIDE FUNCTIONAL OUTPUT C. FUNCTIONAL GATE NOT DESIGNED FOR '1', '0' LOGIC.
- FUNCTIONAL OR GATE FUNCTIONAL INPUTS A OR B PROVIDE FUNCTIONAL OUTPUT C. FUNCTIONAL GATE NOT DESIGNED FOR '1', '0' LOGIC.
- LAMP
- THREE POSITION TOGGLE SWITCH



This diagram is the same as the Level 2, LEM Functional Configuration, Pyrotechnic Subsystem, LDW-540 10002, Rev. A except that the S band antenna deployment function has been deleted

Fig. 3 Pyrotechnic Subsystem Functional Diagram

3. MISSION RELATED DESIGN CRITERIA

3.1 APPLICABLE SPACECRAFT DESIGN GROUND RULES

- The LEM shall be capable of meeting its nominal design performance level for a forty-eight hour mission with a crew of two following separation in lunar orbit.
- The LEM shall be designed to accommodate lunar surface day or night extremes.
- During lunar stay, normal operations permit one man out and one man in the LEM. However, the LEM shall be designed to permit one crewman to effect an unassisted rescue of another on the lunar surface.
- The crewmen will be in spacesuits during all lunar operations.
- Visual LOS from LEM to the landing site is required during the LEM descent phase beginning at 7 - 10 miles slant range from the landing site.
- No attitude constraints shall be imposed on the LEM due to thermal considerations.

3.2 INTERFACE CRITERIA

- The LEM/CSM docking interface shall be designed in accordance with NASA Apollo Docking Interface Ground Rules, Reference 2.
- The LEM structure shall be designed for all imposed loading conditions as delineated in Reference 1.
- The LEM structure shall be designed to experience a vibratory environment as delineated in GAEC Report, "Proposed Vibration Design and Test Procedure for the LEM," Reference 4.
- The LEM shall be supported within the S-IVB adapter from launch until transposition docking by structural outriggers on the descent stage.

4. LEM STRUCTURAL/MECHANICAL SUBSYSTEM CRITICAL DESIGN REQUIREMENTS

4.1 FUNCTIONAL REQUIREMENTS

4.1.1 Passive Thermal Control

The LEM must be protected thermally from the environmental extremes which occur when attached to the CSM during translunar coast, and when separated during lunar flight and stay. The LEM must also be protected from thermal inputs due to descent or ascent engine firings.

4.1.2 Meteoroid Protection

It is essential that the LEM be provided with as much protection from meteoroids as is practical to prevent critical damage of equipment or expendables and possible loss of crew.

4.1.3 Crew Visibility

The visibility through the front windows of the LEM should be such that the crewmen in combination can survey the primary landing site as early as possible or select an alternate site within the ΔV budget. During hover, the windows should allow surveillance of the maximum landing footprint available. The upper window in the LEM should provide a crewman with sufficient visibility to perform the rendezvous docking maneuver.

4.1.4 Crew and Equipment Transfer

The LEM is manned from time of lunar orbit checkout until rendezvous docking. Means must be provided to get the crew from and to the CM while the vehicles are joined and to and from the lunar surface after landing. The crewmen must be able to transfer scientific equipment through each hatch and the probe and drogue through the upper hatch. The crew must also be able to perform an extra-vehicular transfer (EVT) through the front hatch.

4.1.5 Pressurized Cabin

The cabin, which houses the crew during lunar operations, should be capable of holding oxygen at sufficient pressure to allow the crew, when mission phases permit,

to operate without gloves, with open face plate, and without a pressure differential on the suit. The cabin should also be capable of experiencing multiple resurization cycles.

4.1.6 Provide Support for Equipment

The LEM primary structure and secondary equipment supporting structure should sustain without failure the loads imposed by accelerations and vibrations resulting from the launch vehicle, SM and LEM engine thrustings during the mission phases, the loads produced during docking and those imposed during lunar landing. When required, the structure should provide an interface with the equipment that minimizes shock and vibration inputs and holds close tolerance alignment between dependent pieces of equipment and between equipment and body axes.

4.1.7 Provide LEM/CSM Docking Interface

Transposition and rendezvous docking shall be accomplished at one location on LEM. This location should provide an interface with the CSM that permits a structural tie between the vehicles during docking, allows intravehicular transfer of crew and equipment and provides means for any required umbilical connections. This interface with the CSM should be at LEM's upper tunnel and in a plane perpendicular to the X axis. The connection at this interface should allow the use of LEM as a backup propulsion unit for the CSM, Reference 16.

4.1.8 Landing Stability and Impact Attenuation

During a lunar landing, the LEM landing gear must attenuate landing impact loads and assume a stable attitude so that lunar tasks may be performed and a solid platform is provided for launch of the ascent stage.

4.2 DISCUSSION

4.2.1 Passive Thermal Control

The LEM should resist a cold-soak period of up to 110 hours during translunar coast when in the shadow of the CSM, where radiation is minimum, and a heating period of 45 hours during high noon of lunar stay, when the combined radiation from the sun and moon are maximum. The descent engine fires nominally for as long as 9.5 minutes during the powered descent and hover phase, and 12.2 minutes with a minimum descent and maximum hover time. The ascent engine is in continuous operation for as long as 8.5 minutes during the ascent phase.

A means of passive thermal control is required when the LEM is experiencing these conditions. Present analysis indicates the use of multiple layers of aluminized Mylar in a space approximately one-half inch thick between the basic structure and a thin outer metal sheet is satisfactory. The final design will undoubtedly vary layer thickness with location but the distribution can only be determined by full scale model tests.

Thermal protection is also required in the areas subjected to engine heating. This protection has not been designed but will probably consist of layers of nickel foil, Refrasil paper, aluminum foil, and glass paper in a specified order to provide a blanket between the structure and a thin outer metal sheet. The final design will be determined from future tests.

4.2.2 Meteoroid Protection

At present, the basic LEM structure and thermal insulation is the extent of crew and equipment micro-meteoroid protection. With this protection, the probability of mission success is estimated to be .09 and crew safety is estimated to be .52 (Reference 6) when subjected to a meteoroid environment as delineated in Reference 7. Additional protection is obviously needed.

A weight-reliability trade-off study (Reference 6) shows that for a small initial increase in weight, large gains in protection are achieved; but that further weight increments result in relatively smaller gains. The study also indicates that the design objective of .999 mission success (Reference 9) is not attainable without impractical weight penalties.

Maximum protection per practical weight increment is recommended. This is implied in Reference 6 where a dry weight increment of 46 lbs. increases mission success to .893 and crew safety to .973. This weight increment should be amended for an additional 12 lbs. of fittings, increasing the dry weight to 58 lbs. and increasing the separated weight from 160 to 210 lbs.

4.2.3 Crew Visibility

During the descent visibility phase, which begins 7 nautical miles from the nominal aim point, using the normal trajectory described in Reference 10, both crewmen should be able to see the nominal landing site and any alternate site attainable by a reasonable ΔV expenditure. The crewmen should also be able to see the maximum available landing footprint when hovering at 200 feet.

A ΔV expenditure of 400 fps is considered a reasonable operational allowance for alternate site selection and is borrowed from the hover-to-touchdown ΔV budget, as per the following considerations:

350 fps - nominal Reference Mission descent from 200 ft.

400 fps - allowed for flexibility during hover.

400 fps - alternate site selection.

1150 Total Budget For Hover-To-Touchdown

The envelope of possible alternate sites attainable from the start of the visibility phase, 10,000 ft. altitude, and the middle of the visibility phase, 5,000 ft. altitude, was estimated by extrapolating Reference 15 curves. These envelopes are superimposed on the LEM window boundaries in Figure 4 and it is seen that the crew can see most of the attainable sites. Increased pitch attitude would improve the coverage but would increase descent ΔV and thus reduce ΔV available for hover.

When LEM is active during rendezvous docking, it is necessary to visually align the vehicles for engagement of the probe and drogue. This requires that LEM have some sighting aid in the window area and that suitable targets be placed on the CM.

Until recently, when it was decided to eliminate the front docking tunnel and dock with the top tunnel (Reference 3), visibility was obtained through the front windows for docking on the front tunnel and either crewman was able to accomplish the task. It is now necessary to provide a window in the upper cabin structure for visibility during upper tunnel docking maneuvers. As either the LEM or CSM can be active in docking, one upper window over the commander's position has been deemed adequate.

From an average eye position, determined by GAEC, the viewing angles specified in Reference 3 for the upper window are 10° inboard, 10° outboard, 40° forward, and 5° aft. These angles are presumed adequate but will require docking simulations for true evaluation. At the present time, no simulations have been performed using the upper hatch docking configuration with LEM active. These viewing angles also increase the ability of the commander to monitor the guidance operation during ascent where the planned attitude is "belly down".

4.2.4 Crew and Equipment Transfer

The crew must be able to transfer from the CM to the LEM for LEM operations and, after rendezvous, from the LEM to the CM. On the lunar surface, the crew must be able to leave

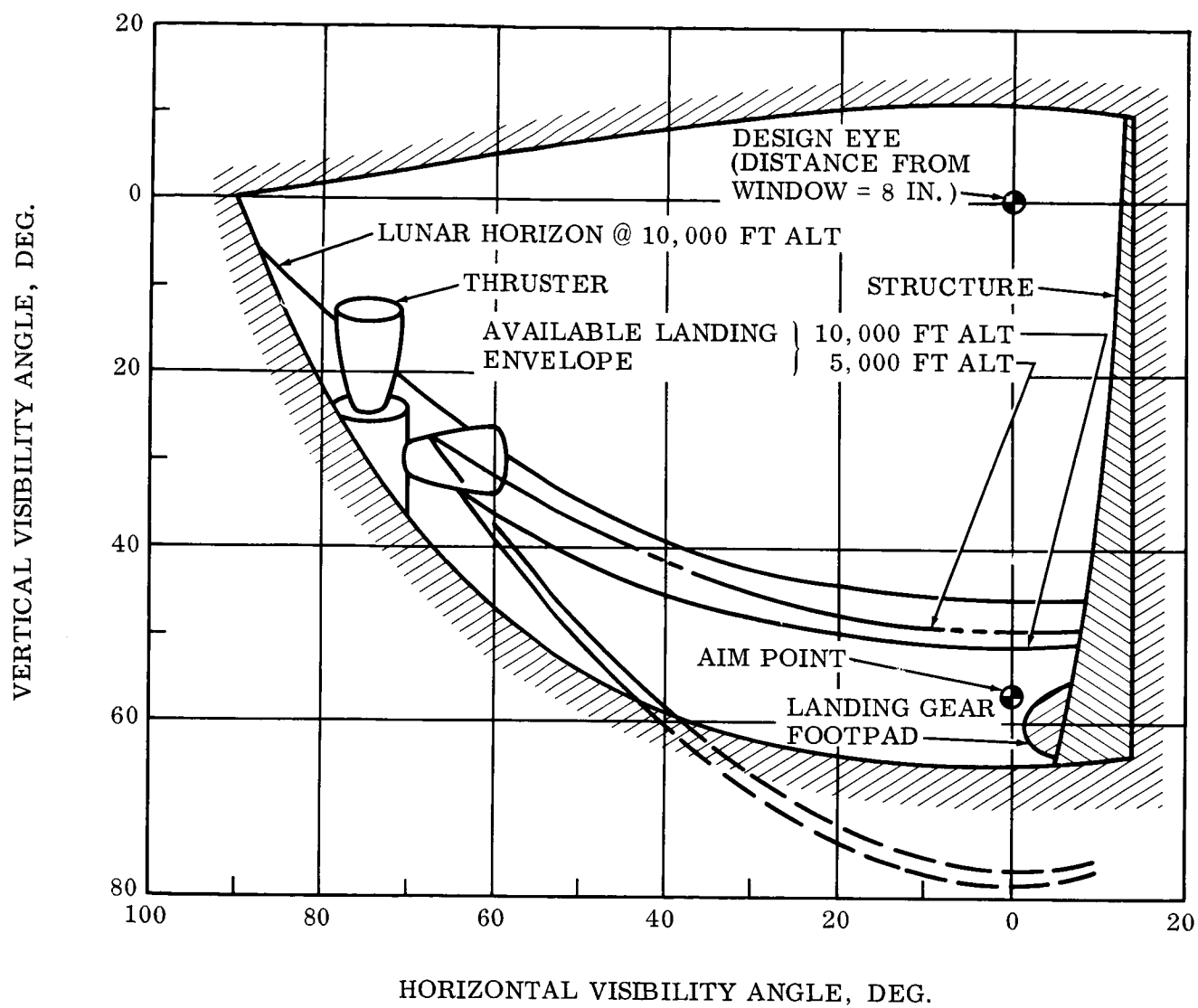


Fig. 4 Forward Window Visibility

and enter the LEM during lunar surface activities. One hatch is required in the docking tunnel and another should provide access to the outside in the event that the tunnel hatch is inoperative. Each hatch must be sized for a crewman in a pressurized suit.

Scientific equipment and lunar samples must pass through the front hatch on the lunar surface and the upper hatch after rendezvous docking. Also, at time of rendezvous docking, the probe and drogue must be brought into the LEM through the upper hatch if the crewman in the CM is incapacitated.

Each hatch should also be capable of being opened or closed from either side, after pressure equalization, in the shortest time possible by a crewman in a pressurized suit, wearing his portable life support system (PLSS) and outer garment in the event a rescue is required.

The size of both hatches was determined by extensive testing which involved the GAEC "Peter Pan" rig and a crewman in an inflated suit wearing a back-pack (PLSS). Test results proved an opening of 32 inches in diameter to be adequate when the crewman is operating in this most critical mode. It also allows passage of the largest scientific unit which is an 8" x 11.5" x 19" specimen return container. The probe and drogue are being designed to collapse for stowage in the CM and will in this configuration pass into the LEM, if required. In the event of a contingency, either hatch may be used for an extra-vehicular transfer at time of rendezvous. Each hatch is hinged into the LEM and has one latch which can be operated from either side. Crew transfer tests are required to determine time of operation.

For descent from the front hatch of LEM to the lunar surface, a platform is provided on the descent stage below the hatch opening. Steps and railings are affixed to the front landing gear leg and extend from the platform to a landing gear pad. Under nominal landing conditions, this means of going to and from the surface is adequate. However, there are landing attitudes within the design envelope that place the pad end of the front gear so far above the surface as to make a controlled descent from the front leg impossible. For this situation, it is desirable to have an alternate means of descending from the front hatch and/or the ability to use the docking hatch with steps down in another direction. At present, there are no provisions for using the upper hatch to transfer a crewman to the lunar surface. The use of the upper hatch requires the removal and stowage of the drogue which is installed in the upper tunnel, and would increase the possibility of damage to the thermal shielding during egress and ingress.

4.2.5 Pressurized Cabin

The LEM is being designed for a nominal pressure level of 5.0 psia in accordance with the Statement of Work, Reference 12, and the justification of this level from a physiological viewpoint is not questioned herein. This pressure is also specified for the CM, and the LEM cabin must be designed for compatibility during crew transfer regardless of a possible lower operating pressure when separated. The cabin structure is designed for multiple repressurizations and does not depend on pressure for efficient operation. Tolerances of the inflow pressure regulation valve and the cabin pressure relief valve will allow, in the worst case, a maximum cabin pressure differential of 5.8 psi. Using a safety factor of 2.0, the cabin structure is designed for 11.6 psi.

4.2.6 Provide Support for Equipment

The LEM structure (Figures 1 and 2) is being designed to withstand all loads imposed by accelerations and vibrations resulting from thrusting of engines as required by the mission phase (see Table I and Reference 4). The maximum accelerations during boost phases are stipulated by MSC in Reference 13. The accelerations during the LEM powered phases were determined using a 25,000 lb. LEM at separation. Use of a higher weight would reduce the values of acceleration but these have been left conservative. Supports for critical equipment are designed using loads with high "g" factors to ensure no detrimental effects to the equipment due to vibratory inputs from the primary structure.

The most severe loading condition at the docking interface could occur with the Service Propulsion System at maximum thrust, hard over gimbal angle, and 1/4 full SM tanks. Although this condition could exceed current design strength, it is a result of multiple failures, and the project is now studying whether it should be included as a design requirement.

The aft bay equipment supporting structure is of tubular construction to permit the circulation of a water glycol mixture that provides a heat sink for critical electronic assemblies. Provisions are made in this area to route and secure all inter-unit cables and piping.

The structure which supports equipment requiring accurate angular alignment relative to body axes or to other units is being designed to satisfy the estimated alignment tolerances in Reference 11. At this point in the development of the LEM structure, it is difficult to determine if all of these requirements can be met within reasonable weight limitations. In particular, a problem may exist in meeting the alignment requirements of 3 - 6 minutes of arc between the landing radar antenna and the navigation base. A study should be made of

the trade between guidance accuracy and structural weight to determine the penalties of accepting a less stringent alignment tolerance.

4.2.7 Provide LEM/CSM Docking Interface

The LEM must be capable of being joined to the CSM during transposition docking and after lunar ascent during rendezvous docking. This joining must result in a structural tie between the LEM and the CSM so that behavior is correct during SM engine and RCS firings. An electrical umbilical is required in this area for transmitting signals which jettison the S-IVB and for the monitoring of LEM's cabin pressure from the CM during the translunar coast phase.

The position of LEM relative to the CSM should align as closely as possible their respective C. G.'s and the LEM and SM engine centerlines to reduce control moment requirements during thrusting phases.

The LEM side of the LEM/CSM structural interface is being designed to distribute the loads imposed during the midcourse corrections and lunar orbit insertion phases of the mission. These loads result from combination of thrust buildup and SM engine gimbal angle, and vary with the fuel quantity in the SM tanks. The maximum values of axial (compressive), shear, and moment loadings do not occur simultaneously so the highest value in each combination is used. The values given in Table I are limit loads and, with the exception of the 23,300 lb. axial load, are based on NAA dynamic analysis studies published in Reference 5. The 23,300 lb. axial load was determined by GAEC and is higher than any axial load listed in Reference 5. It is the result of maximum SPS thrust buildup, 1.3 degree engine gimbal angle and SM fuel tanks 1/4 full.

At present, design loads imposed by the docking maneuver have not been determined. They will be a function of the NAA designed probe and drogue attenuation system which should accommodate the impact conditions listed in the MSC docking interface ground rules, Reference 2. The ground rules are the results from a series of MSC/contractor discussions and it is not possible to make any additional contribution at this time. These impact conditions, however, are subject to review and require confirmation by simulation.

The longitudinal centerlines of the ascent and descent engines coincide and are normal to and intersect the center of the LEM/CSM docking interface plane. Within the docking tunnel are provisions for mounting receptacles compatible with the umbilical from the CM.

4.2.8 Landing Stability and Impact Attenuation

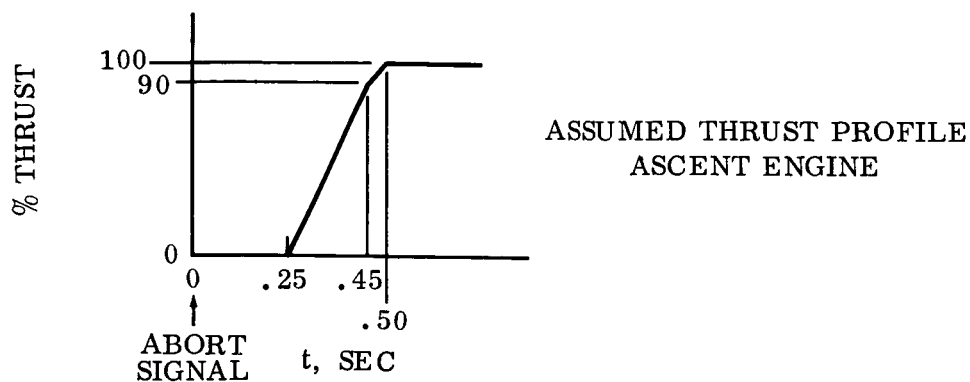
There are two capabilities required of the LEM's landing gear. One is the ability to maintain a stable attitude without tipping over after experiencing a "worst landing configuration" described in Table I. The other is the ability to absorb energy produced by any combination of impact velocities of 10 ft./sec. vertical, 5 ft./sec. horizontal, and 5° /sec. rotation about any axis when the landing conditions are as listed in Table I.

The vertical and horizontal impact velocities are defined in the Statement of Work, Reference 12, as requirements for the propulsion system. The rotational velocity is an arbitrary figure assumed for early studies which simulator results have since indicated to be conservative, (Reference 14). The landing conditions in Table I are the results of studies using the lunar surface model and seem reasonable, based on present knowledge. As a result of landing simulation runs, the impact velocities noted above, which are being used for the landing gear design, appear satisfactory.

However, with the errors inherent in the altitude indication loop in combination with an engine cutoff or failure close to the surface, the vertical velocity can be greater than 10 ft./sec. An example is shown in Figure 5. If shutdown occurs at point A with an indicated altitude and velocity of 8.6 feet and 1.8 ft./sec. respectively, it is possible with a three sigma velocity and altitude error, to be at 13.6 feet with a 2.8 ft./sec. descent velocity, point B, and therefore touch down with a resultant impact velocity of 12.4 ft./sec. Landing approaches should be made below the abort boundary where it is possible to initiate an abort and separate from the descent stage as the landing gear is just impacting the surface.

In order to more accurately determine the altitude prior to touchdown, the concept of a feeler probe is considered feasible. The probe could actuate engine cut off on contact with the lunar surface. The design and reliability of such a probe warrants study.

At present, the gear is being designed per conditions in Table I with four primary struts that attenuate compression loads and eight secondary struts that attenuate compression and tension loads. Each primary strut with its two associated secondary struts acts independent of the other primary and secondary struts so that a $\pm 5^{\circ}$ pitch and roll angle and a surface as per Reference 8 can be accommodated. At the end of each primary strut is a pad with pivotal movement capable of landing on soil having a minimum bearing strength of 12 psi.



3σ ALTITUDE ERROR, ± 5.0 FT
 3σ VELOCITY ERROR, ± 1.0 FT/SEC

EXAMPLE:

POINT A, INDICATED CONDITIONS

POINT B, ACTUAL CONDITION WITH -5 FT ALT ERROR AND -1 FT/SEC
 VELOCITY ERROR. IMPACT VELOCITY WILL BE 12.4 FT/SEC

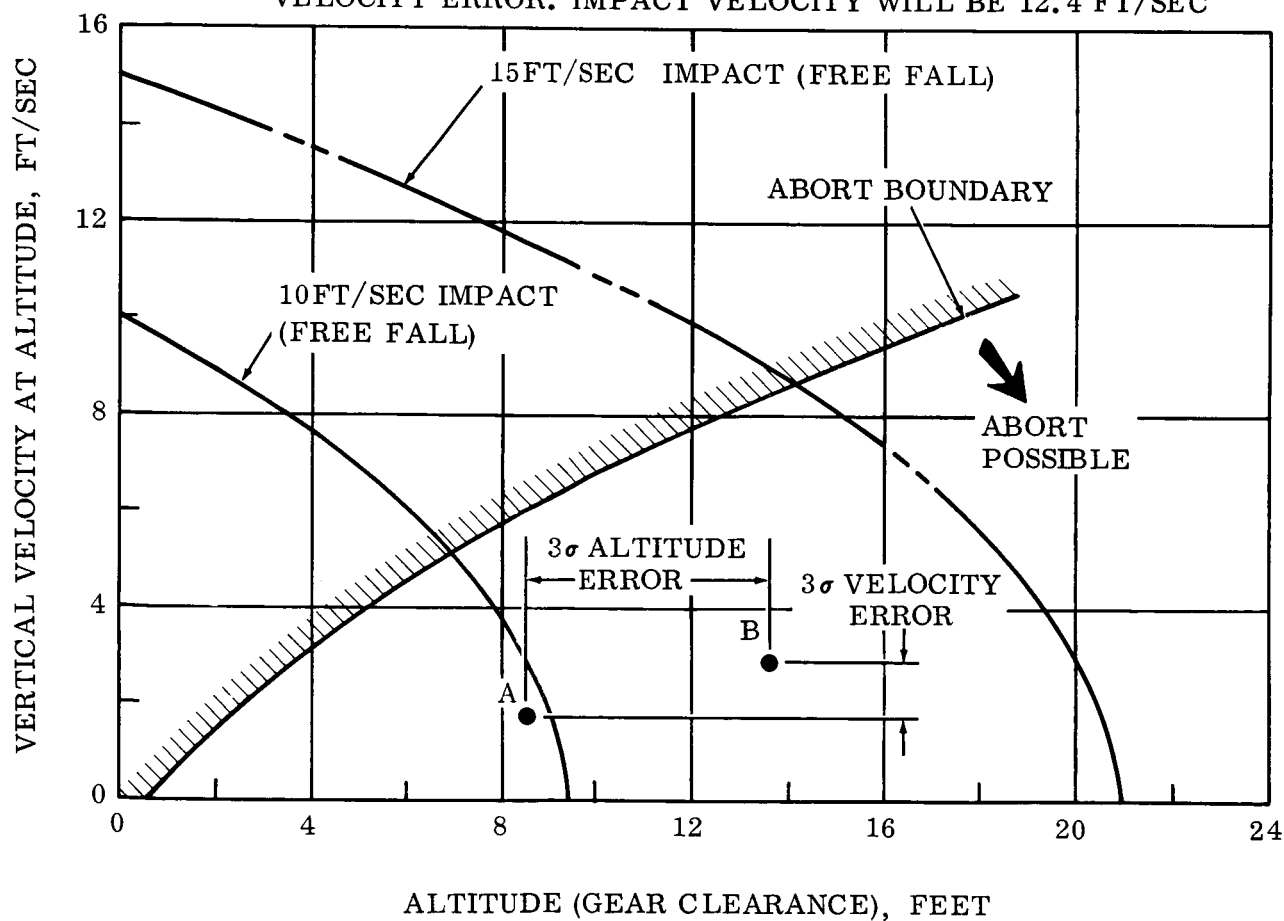


Fig. 5 Initial Conditions for Impact Velocities and Abort Boundary

5. CONCLUSIONS

In most areas, the present structural/mechanical design of LEM is capable of meeting mission-related requirements if environmental conditions are within the assumed envelope. Qualifications and exceptions are presented below:

- The present thermal insulation and its distribution must be verified by tests.
- Meteoroid protection is not adequate and shielding should be added to raise the level of crew safety from an estimated .52 to .97. Separation weight would be increased 210 pounds.
- The upper docking window is a recent design addition and its visibility must be verified by rendezvous docking simulations.
- Descent of the astronaut to the lunar surface presents a problem when the LEM is tipped back. A means should be provided for access to the surface under this condition.
- Aside from CM compatibility, the need for a 5 psia cabin pressure level does not appear to be rigorously justifiable. However, since the structural weight saving effected by reducing the pressure to 3.7 psia would be less than 50 pounds, this change is not recommended at this time.
- A study should be made of the trade between guidance accuracy and structural weight to determine the penalties of accepting a less stringent tolerance between the landing radar and the navigation base.
- Docking impact loads are lacking. The CM/LEM interface is being designed for SM thrusting loads which are assumed adequate for docking.
- The possible errors in altitude and velocity measurements are such that premature descent engine shutdown near the lunar surface could result in touchdown velocities exceeding the specified landing gear design capability. Design and reliability studies should be conducted of a feeler probe which will shut down the descent engine upon lunar surface contact.

6. REFERENCES

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TABLE I, STRUCTURAL/MECHANICAL REQUIREMENTS SUMMARY

SUBSYSTEM FUNCTION	PARAMETERS WHICH DESCRIBE FUNCTIONS	MISSION EVENTS OR PROFILE WHICH SIZE PARAMETER, AND VALUE	CURRENT DESIGN VALUE
4.2.1 Passive Thermal Control	Insulation thick- ness (solar radia- tion) Insulation thick- ness (engine radiation)	<u>Normal</u> : 45 hour sur- face stay at high noon, 110 hour shadow trans- lunar coast. See Text. <u>Contingency</u> : 220 hrs (LEM backup of SPS) <u>Normal</u> : During operation of engines. See Text. <u>Contingency</u> : None	Approximately 25 layers NRC-2 in 1/2" space between thin sheet of aluminum and basic structure. Possible use of multiple layers of nickel foil, Refrasil spacers, alumi- num foil and glass paper to form a blanket between a thin sheet of titanium and basic structure. (thick- ness not determined)
4.2.2 Meteoroid Protection	Distribution of external material	<u>Normal</u> : Environ- ment as described in Reference 7. See text for discussion of value. <u>Contingency</u> : Shower not designed for.	Protection inherent in basic structure and thermal shielding.
4.2.3 Crew Visi- bility for landing	Distribution of viewing angles during powered descent and hover.	<u>Normal</u> : Both crew- man to see: Down - LOS to nominal and attainable alternate landing sites from 7 nautical mile range - 79° down Side - Maximum aximuth view of horizon during hover Up - View of horizon during hover - 10° up for 10° tilt. <u>Contingency</u> : None	From normal eye position, 65° down 12 1/2° inboard 90° outboard 11° up (See Figure 4)

TABLE I, STRUCTURAL/MECHANICAL REQUIREMENTS SUMMARY (Cont)

SUBSYSTEM FUNCTION	PARAMETERS WHICH DESCRIBE FUNCTIONS	MISSION EVENTS OR PROFILE WHICH SIZE PARAMETER, AND VALUE	CURRENT DESIGN VALUE
4.2.3 Crew Visibility for ascent and docking	Distribution of viewing angles	<u>Normal</u> : Commander to see: Horizon during ascent, CSM during docking. See text. <u>Contingency</u> : None	From average docking eye position: 10° inboard 10° outboard 40° forward 5° aft
4.2.4 Crew and Equipment Transfer to and from: C/SM	Upper hatch size	<u>Normal</u> : Crew member in uninflated suit, 29 inch diameter opening required. <u>Contingency</u> : With inflated suit wearing back pack (PLSS.) 32" dia. needed.	32 inch diameter opening
Lunar Surface or for EVT.	Forward hatch Size	<u>Normal</u> : Crew member in inflated suit wearing backpack (PLSS) <u>Contingency</u> : None	32 inch diameter opening
Lunar Surface	Ladder requirement	<u>Normal</u> : From forward hatch to surface with LEM tipped back 16°. Ladder with hand grips to extend down from forward hatch to surface <u>Contingency</u> : LEM tipped back 30° (max. angle which allows alignment of abort guidance unit)	From forward hatch to pad on strut. See Figure 1

TABLE I, STRUCTURAL/MECHANICAL REQUIREMENTS SUMMARY (Cont)

SUBSYSTEM FUNCTION	PARAMETERS WHICH DESCRIBE FUNCTIONS	MISSION EVENTS OR PROFILE WHICH SIZE PARAMETER, AND VALUE	CURRENT DESIGN VALUE
4.2.5 Pressurized Cabin	Cabin pressure	<p><u>Normal:</u> Compatibility with the work statement and the CM: 5.0 psi.</p> <p><u>Contingency:</u> Failure of O₂ supply pressure regulator; 5.8 psi (upper limit of relief valves). Provide margin above 3.5 psi for two minutes after 1/2 hole in cabin; 4 to 4 1/2 psi.</p>	0 to 11.6 psi (With Safety Factor of 2.0)
4.2.6 Provide Support Structure for Equipment	<p>Max. accelerations during ascent phase</p> <p>Vibrations - through out engine thrusting phases</p> <p>Alignment</p>	<p><u>Normal:</u> Ascent engine burnout and RCS thrusts: +1.0g, -.10g, ±0.88 rad/sec², X axis ±0.05g, ±0.88 rad/sec², Y axis ±0.05g, ±2.0 rad/sec², Z axis</p> <p><u>Contingency:</u> None</p> <p><u>Normal:</u> Random vibrations - Input to equipment supports from primary structure: Frequencies from 10 thru 2,000 cps with appropriate power spectral density.</p> <p><u>Contingency:</u> None</p> <p>See Text</p>	<p>Same</p> <p>Same</p>

SUBSYSTEM FUNCTION	PARAMETERS WHICH DESCRIBE FUNCTION	MISSION EVENTS OR PROFILE WHICH SIZE PARAMETER, AND VALUE	CURRENT DESIGN VALUE
4.2.6 Provide Support Structure for Equipment (Cont)	Max. accelerations during boost and translunar injection	<u>Normal</u> : During SIC boost, + 4.7 g X axis. At SIC cutoff, - 2.6 g X axis. With SII engine hardover, $\pm .63$ g Y and Z axis <u>Contingency</u> : SIVB hardover at burnout: $\pm .70$ rad/sec ² about Y and Z axes.	Same
	Max. accelerations during powered descent phase	<u>Normal</u> : Descent engine maximum thrust at burnout plus RCS thrusts: + 1.1 g, $\pm .31$ rad/ sec ² , X axis <u>Contingency</u> : Descent engine hardover at maximum thrust at burnout plus worst RCS combinations. $\pm .11$ g and $\pm .47$ rad/ sec ² , Y and Z axes	Same
4.2.7 Provide LEM/CSM Docking Interface	Max. loads during SM thrusting	<u>Normal</u> : Lunar orbit insertion SM tanks 1/4 full; 23,300 lbs. axial. Mid-course correc- tion; (full SM tanks) 2,000 lbs. shear, 307,000 in. lbs. moment. <u>Contingency</u> : Maxi- mum thrust build up with full gimbal angle	Same conditions See Text

TABLE I, STRUCTURAL/MECHANICAL REQUIREMENTS SUMMARY (Cont)

SUBSYSTEM FUNCTION	PARAMETERS WHICH DESCRIBE FUNCTION	MISSION EVENTS OR PROFILE WHICH SIZE PARAMETER, AND VALUE	CURRENT DESIGN VALUE
4.2.7 Provide LEM CSM Docking Interface (Cont)	Max. loads during docking, after transposition and after rendezvous	<u>Normal</u> : Probe engagement of drogue. Values not presently available. See text. <u>Contingency</u> : None	Not determined
4.2.8 Provide Landing Stability and Impact Attenuation (See Figure 2)	Gear geometry (Stability)	<u>Normal</u> : LEM pitched up 5° landing on 5° down hill slope with horizontal velocity of 5 ft/sec. In direction of motion (yawed condition), two aft legs land in shallow constraining holes and two forward legs pitch into 24 inch deep holes. <u>Contingency</u> : None	Same condition.
	Energy absorption Capability	<u>Normal</u> : Determined by the following three conditions with vertical velocity of 10 ft/sec., horizontal velocity of 5 ft./sec. and rotational velocity of 5°/sec. about any axis at impact: 1. LEM pitched 5° down landing on 5° up-hill slope. Lead leg hits restraint producing max. compression in secondary lead struts.	Same conditions

TABLE I, STRUCTURAL/MECHANICAL REQUIREMENTS SUMMARY (Cont)

SUBSYSTEM FUNCTION	PARAMETERS WHICH DESCRIBE FUNCTION	MISSION EVENTS OR PROFILE WHICH SIZE PARAMETER, AND VALUE	CURRENT DESIGN VALUE
<p>4.2.8</p> <p>Provide Landing Stability and Impact Attenuation (Cont)</p>	<p>Energy absorption capability (cont)</p>	<p>2. LEM pitched 5° down landing on 5° up- hill slope. Two oppo- site legs hit curb while leading leg contacts smooth low friction terrain producing max. tension in secondary side struts.</p> <p>3. LEM pitched 5° up landing on 5° down- hill slope. Trailing leg lands first in small hole and side legs pitch into 24 inch deep holes producing maximum compression in lead primary structure.</p> <p><u>Contingency: None</u></p>	<p>Same conditions</p> <p>Same conditions</p>